УНИВЕРЗИТЕТ У НОВОМ САДУ
ГРАЂЕВИНСКИ ФАКУЛТЕТ
СУБОТИЦА

ЗБОРНИК РАДОВА
6. МЕЂУНАРОДНЕ КОНФЕРЕНЦИЈЕ
САВРЕМЕНА ДОСТИГНУЋА У ГРАЂЕВИНАРСТВУ 2018.

CONFERENCE PROCEEDINGS
6th INTERNATIONAL CONFERENCE
CONTEMPORARY ACHIEVEMENTS IN CIVIL ENGINEERING 2018

FACULTY OF CIVIL ENGINEERING

СУБОТИЦА
2018.

IN SITU EXPERIMENTAL DETERMINATION OF THE HEAT TRANSMITTANCE OF A BUILDING WALL

Milica Mirković Marjanović[1]
Zorana Petojević[2]
Radovan Gospavić[3]
Goran Todorović[4]

UDK: 536.2.022:692.23
DOI: 10.14415/konferencijaGFS2018.027

Summary: *In this paper, results of a long term experimental in-situ measurement of air temperatures and heat fluxes trough a building wall surfaces, are presented. Indoor and outdoor measurements were carried out simultaneously during the period of 1 month in a dwelling of residential building located in Belgrade, Serbia. The data were used to calculate the thermal transmittance of the wall according Standard ISO 9869-1:2014. The U-value obtained from the experimental data and those calculated in steady-state temperature regime are compared. Criteria for the data that have to be met in order to get accurate U-value are discussed.*

Key words*: temperature measurement, thermal flux measurement, thermal transmittance*

1. INTRODUCTION

Thermal envelope of a building plays an important role in buildings' energy performance and its characterization during building exploitation is necessary.

The most frequently, the thermal transmittance (U-value), as a key thermal parameter of an envelope is calculated. There are two approaches to obtaining U-value: using wall's layers composition and physical and thermal characteristics of materials or making appropriate in-situ measurements. In the former case calculated U-value is based on steady-state condition and in the latter U-value reflects actual physical condition of an building's element and is obtained in a dynamical thermal regime [1].

Comparison of the U-values between the two approaches often gives useful insight in present envelope condition.

In dynamical regime U-value is defined as the ration of the mean heat flow rate per unit of area divided by the mean air temperature difference between the surroundings on each

---

[1] Milica Mirković Marjanović, PhD student, Institute IMS, Bulevar vojvodeMišića 43, 11000 Belgrade, Serbia, tel: +381648897990, e-mail: milica.mirkovic@institutims.rs

[2] Zorana Petojević, teaching assistant-PhD student, University of Belgrade, Faculty of Civil Engineering Belgrade, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia, tel: +381641306101, e-mail: zjovanovic@grf.bg.ac.rs

[3] Radovan Gospavić, professor assistant, University of Belgrade, Faculty of Civil Engineering Belgrade, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia, tel: +381113218584, e-mail: gospavic@grf.bg.ac.rs

[4] Goran Todorović, professor,University of Belgrade, Faculty of Civil Engineering Belgrade, Bulevarkralja Aleksandra 73, 11000 Belgrade, Serbia, tel: +381113218584, e-mail: todor@grf.bg.ac.rs

side of the wall. In the steady-state regime U-value is the ratio of stady-state heat flux rate per unit area and difference of constant air temperatures of surroundings [2]. Obtaining U-value from the in-situ measurement looks rather simple in theory but in practice there are lot of metrological and practical issues that can lead to significant errors and uncertainties, as demonstrated in the article [3]. In particular, abrupt variations of outdoor temperatures, wind velocity, solar radiation, and thermal inertia of the envelope component under investigation cause U-value dependent of sampling frequency and duration. Also convective heat transfer coefficient are highly sensitive to environment conditions [4].

In this paper we present procedure of the U-value determination by means of in-situ measurement according to Standard ISO 9869-1:2014. It consists of monitoring the heat flux rate passing through façade wall and the indoor and outdoor environmental temperatures. The measurements were made in a room on the fourth floor of residential building in Belgrade. According the Standard average method is used to obtain U-value. This U-value and those obtained assuming steady-state temperature regime are compared.

2. EXPERIMENTAL MEASUREMENTS

2.1. EXPERIMENTAL SETUP

The experimental data were obtained in simultaneous in-situ measurements of inside and outside air temperatures and thermal flux trough the façade wall's surfaces during the period of 1 months of a building located in Belgrade, Serbia. Subjected façade wall faces north and it is protected from direct influence of the solar radiation. The wall was multilayered with five homogeneous layer. The thicknesses and the thermal conductivity of each layer is shown in Table 1.

Instrumentation consisted of the heat flux meter green TEG gSKIN®XO and the two thermocouples sensors NiCr-Ni. The data were collected simultaneously every 5 minutes from the 1thof November to the 1th December 2016. The heat flux meter used and his adapter connector were shown in Figures 1 and 2.

Table 1. Physics parameters of the façade wall

Num.	Layer	Thickness d [mm]	Thermal conductivity λ [W/m·K]
1	Interior plaster	0.03	0.70
2	Clay block	0.25	0.47
3	Plaster	0.01	0,85
4	Mineral rock wool	0.12	0.034
5	Exterior façade plaster	0.02	0.70

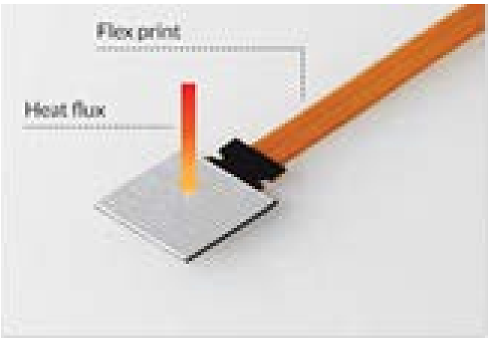

Figure 1. Silicon "g-Skin" flux meter sensor

Figure 2. Flux meter data logger with surface connector

The thermocouples are connected to a digital logger of temperature range: -200°C to +1200°C. The logger has reference junction temperature of 0°C automatically adjusted. Response time function to step excitation in air is 15s and sensitivity approximately 41μV/°C. Silicone green Teg gSKIN®XO heat flux meter is used to measure the heat flow rate. The dimension of the heat flux meter are 30mm x 30 mm x 2 mm, operating temperature range is -50 to 150 ^{0}C, and minimum sensitivity is 7 μV/(W/m^2). The position of the sensors on the wall surfaces are shown in Figures 3 and 4.

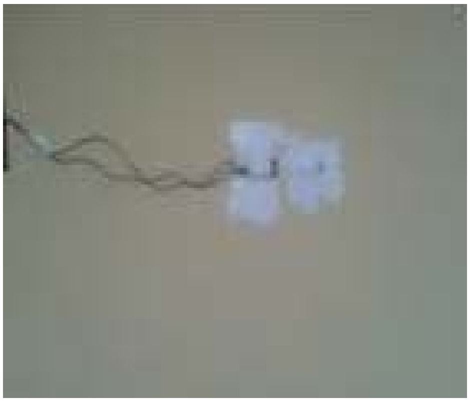

Figure 3. The measurement site on the façade wall outside

Figure 4. The measurement site on the internal façade wall

3. AVERAGE METHOD FOR THE THERMAL TRANSMITTANCE CALCULATION

Requirement of standard ISO 9869-1:2014 to maintain heat flux and surrounding's temperature constant over measurement period is possible to comply only in laboratory environment. In an in-situ procedure the requirement is replaced with condition that mean heat flux rate and mean temperature difference be constant at least same prescribed period. This is valid upon the following conditions: thermal characteristics of materials and heat transfer coefficients are constant over the range of experimental temperatures, and stored heat in the wall is negligible to heat going through the wall.
Thus, the average method assumes that U-value can be obtained using eq. (1) :

$$\mathrm{U} = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n} \left(T_{ij} - T_{ej}\right)} \qquad (1)$$

where q is the density of the heat flow rate per unit area, T_i [K]is the air temperature measurement inside and T_e [K] is the air temperature measurement outside.

In this paper, instead of sums in Eq.(1), we use integrals. In this way q, T_{ij} and T_{ej} are treated as continuous functions of time $q(\tau)$, $T_i(\tau)$ and $T_e(\tau)$:

$$\sum_{j=1}^{n} q_j = \frac{1}{T} \int_0^{\tau} q(\tau) d\tau \qquad (2)$$

$$\sum_{j=1}^{n} \left(T_{ij} - T_{ej}\right) = \frac{1}{T} \int_0^{\tau} \left(T_i(\tau) - T_e(\tau)\right) d\tau \qquad (3)$$

Eq.(1) becomes:

$$\mathrm{U} = \frac{\int_0^{\tau} q(\tau) d\tau}{\int_0^{\tau} \left(T_i(\tau) - T_e(\tau)\right) d\tau} \qquad (4)$$

Thermal transmittance in steady-state conditions is given in equation (5):

$$\mathrm{U} = \frac{1}{R_{si} + \sum_{1}^{i} \frac{d_i}{\lambda_i} + R_{se}} \qquad (5)$$

where R_{si} and R_{se} are surface thermal resistance in m^2K/W, d_i and λ_i are thickness and coefficient of thermal conductivity of each layer respectively. For façade wall these values are: $R_{si}=0.13\ m^2K/W$ and $R_{se}=0.04\ m^2K/W$.

4. EXPERIMENTAL RESULTS AND DISCUSION

In Figure 5 the measured values of indoor and outdoor temperature of air of the apartment, located of the fourth floor of a four-storey residential building in the Belgrade were shown. The temperatures were collected in every 5 minutes in the period from the 1st November till 30th November 2016. thermocouples type K (NiCr-Ni) in the heating season. The graphics curves contain 8107 measurement points. The red curve of the image corresponds to the indoor air temperature, and the blue corresponds to the outdoor temperature. The amplitude of the graphics corresponds to the change of day and night. The temperature difference between indoor and outdoor temperature were shown in Figure 6.

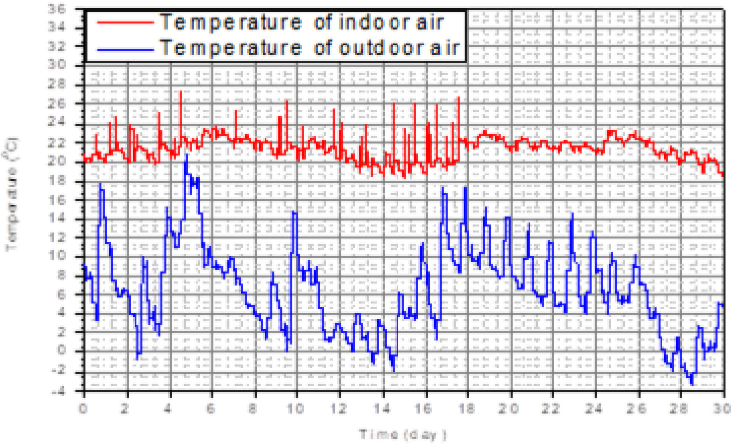

Figure 5. The indoor and outdoor temperature of air in the period from the 1st till 30th November 2016.

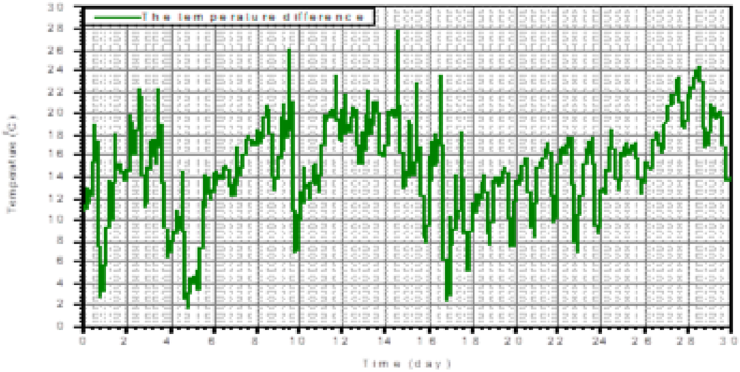

Figure 6. The temperature difference between indoor and outdoor temperature of air in the period from the 1st till 30th November 2016.

In Figure 7 the measured values of density of heat flux was shown. As at the Figure 5 the amplitudes represent the daily temperature variation. The data of heat flux density and indoor and outdoor temperature were collected in the same time in every 5 minutes. In accordance with Equation (4), the thermal transmittance is obtained as the ration of the mean heat flux density divided with the mean temperature difference of surrounding air and is was shown in Figure 8.

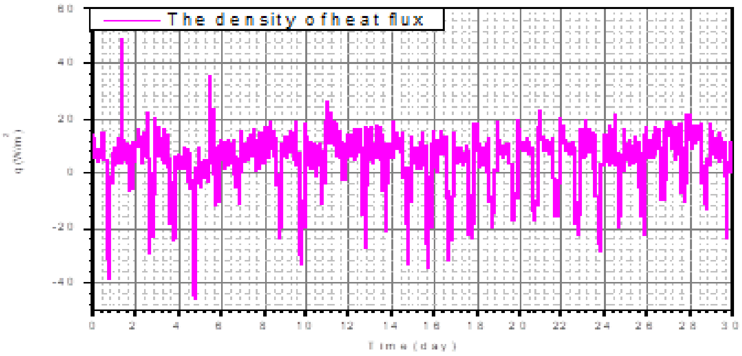

Figure 7. The density of heat flux in the period from the 1st till 30th November 2016.

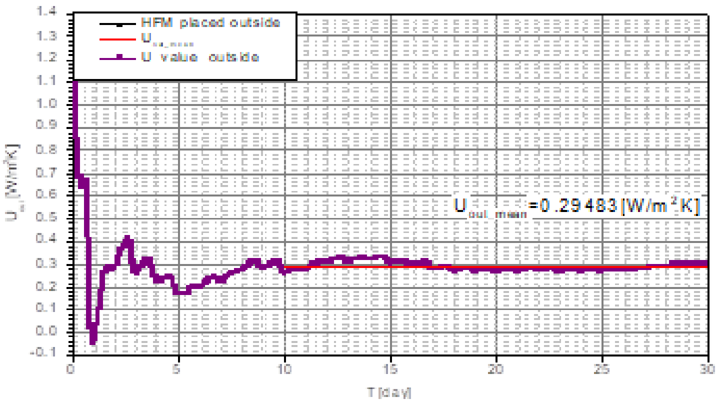

Figure 8. The thermal transmittance obtained in-situ measurements according Eq.(4)

Standard ISO 9869-1:2014 prescribes at least 3day period of measurement and that the thermal transmittance obtained in the last 24 h of test does not deviate more than 5% . As we can see from Figure 8 in the first 8 days U-values strongly oscillates and value are out of 5% range. Also, according the standard, U-value obtained by analyzing the data from the first time period during INT(2 x DT/3) days should not deviate by more than ± 5 % from the values obtained from the data of the last time period of the same duration. DT is the duration of the test in days; INT is the integer function. In our case, the data were collected 30 days. That means that our thermal transmittance in the last 24 hour and in the last 20 days does not deviate more than 5%. The mean value of thermal transmittance in the period of 30day is $U_{mean}=0.29483$ W/(m^{2}K). The value was compared with theoretical one obtained in steady state condition according with Equation 5. In steady state conditions the thermal transmittance amounts to U=0.24128 W/(m^{2}K). The thermal transmittance obtained in steady state conditions is 18.16% lover then the same using the average method.

5. CONCLUSION

In this paper, results of a long term experimental in-situ measurement required for evaluation of the thermal transmittance (U-value) of building wall, are presented. Experimental methods are based on in situ data according non-destructive method standardized by ISO 9869-1:2014 that consists of monitoring the heat flux rate passing through the façade wall and the indoor and outdoor environmental temperatures to obtain the thermal transmittance. Average method is used to obtain U-value. The U-value obtained from the experimental data and those calculated in steady-state temperature regime are compared. The U-value of facade wall being higher 18.16 % than that design standard in steady-state conditions. For this reason, the in situ measurement in the wall U-value is an important auxiliary measure to guarantee the actual thermal insulation of building envelopes.

REFERENCES

[1] Ellena Luchi: “Thermal transmittance of historical brick masonries: A comparison among standard data, analytical calculation procedures, and in-situ heat flow meter measurements”, Energy and Buildings 134 (2017), pages 171-184.
[2] ISO 9869-1:“Thermal insulation -Building elements - *In-situ* measurement of thermal resistance and thermal transmittance - Part 1: Heat flow meter method
[3] Giorgo Ficco, Fabio Iannetta, Elvira Ianniello, Francesca Romana d’ Ambrosio Alfano, Marco Dell’Isola: “U-value in situ measurement for energy diagnosis of existing buildings”, Energy and Buildings 104 (2015), pages 108-121.
[4] Milica Mirković, Marina Aškrabić, Zorana Petojević, Goran Todorović, Radovan Gospavić: „Determination of convective heat transfer coefficient of a facade wall by long- term measurements”, Society for materials and structures testing of Serbia, XXVII Congress, Vršac October 18-20, 2017. pages 499-504.

ODREĐIVANJE KOEFICIJENTA PROLAZA TOPLOTE KROZ FASADNI ZID EKSPERIMENTALNIM MERENJEM

Rezime:*U radu su prikazani rezultati dugoročnog in-situ merenja temperatura vazduha i toplotnih flukseva na površinama zida. Merenja su vršena istovremena unutar i van* *prostorije jedne stambene zgrade u Beogradu tokom 1 meseca. Izmerene vrednosti su korišćene za izračunavanje koeficijenta prolaza toplote, tj. U-vrednosti fasadnog zida prema Standardu ISO 9869-1:2014. Dobijena U-vrednost je upoređena sa koeficijentom prolaza toplote dobijenim izračunavanjem za isti zid u stacionarnom stanju. Diskutovani su uslovi pod kojim merene vrednosti se mogukoristiti za izračunavanje tačne vrednosti koeficijenta prolaza toplote.*

Ključne reči*: merenje temperature, merenje toplotnog fluksa, koeficijent prolaza toplote*